The Same Iron Has No Direction as a Sphere and Thirty-Eight Times the Crystal's as a Thin Film

— the shape anisotropy of an iron thin film, 1.837266×10^6 J/m^3, is **38.276379** times the magnetocrystalline anisotropy of the same iron, 4.8×10^4 J/m^3 — the separator is shape versus crystal structure — [Paper 665]

Yuuki YAMAGISHI (山岸 勇輝)
Yamagishi Complexity Torus Lab, Japan
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— *From thinking to syncing.* —

Abstract

It is natural to think that which way a magnet prefers to point is set by its material. But the same iron points equally in every direction as a sphere and strongly in plane as a thin film.The anisotropy made by shape and the anisotropy made by the crystal are counted side by side in the same units.No new theorem or law is claimed. First, and this is the core. In a thin film, shape far outweighs the crystal——the shape anisotropy of an iron film, 1.837266×10^6 J/m^3, is 38.276379 times the magnetocrystalline anisotropy of 4.8×10^4 J/m^3 (Section 2). **Second, for a sphere the effect of shape vanishes exactly——the demagnetizing factor of a sphere is 1/3 in all three directions, so every direction costs the same and the shape anisotropy is 0. Only the crystal remains** (Section 2). **Third, shape catches the crystal after only a slight stretch——raising the axial ratio of a prolate spheroid from 1 gives 2.765597×10^5 J/m^3 at 1.5, 4.403082×10^5 at 2 and 8.627273×10^5 at 10; for iron the two are equal at an axial ratio of 1.068187** (Section 3). **Fourth, which one wins changes with the material——the same thin-film ratio is 38.276379 for iron and 32.843606 for nickel, but 2.736676 for cobalt, where the crystal comes level** (Section 2). **Fifth, the field required differs by orders as well——turning the magnetization of an iron film out of the plane takes a field equivalent to 2.148849 T, whereas the crystal alone would need only 0.056140 T** (Section 3). **Sixth, the separator is shape versus crystal structure——change only the shape, with the material fixed, and the anisotropy moves between 0 and tens of times the crystal's** (Section 4). **Keywords**: magnetic anisotropy, shape anisotropy, demagnetizing factor, saturation magnetization, magnetocrystalline anisotropy, thin film.

Scope of this paper (scope note): **No new theorem or law is claimed——demagnetizing factors (Osborn 1945), shape and magnetocrystalline anisotropy, and the definition of the anisotropy field are all standard (Cullity and Graham 2009).Domains are not treated——domain walls, domain structure and the mechanism of coercivity are not the subject. Only the size of the energy of a uniformly magnetized body is examined.Representative values are used——the saturation magnetizations and anisotropy constants are room-temperature representative values, not measurements of particular samples.Other anisotropies are not included——surface anisotropy, magnetoelastic anisotropy and induced anisotropy from deposition are not treated.No magnetic recording is designed——areal density, choice of media and writing schemes are not entered into.Relation to earlier papers**: **Paper 419 showed that the same material and the same shape differ in strength with orientation, where it was the process, the direction of the layers, that cut a direction into the material——here it is the shape itself that cuts one. How easily magnetization turns moves, with the material fixed, from 0 to tens of times the crystal's.**What is added is **setting shape and crystal anisotropy side by side in the same units for three materials**, **showing from the sum of demagnetizing factors that a sphere gives exactly 0**, **inverting for the axial ratio at which shape matches the crystal**, and **placing the separator on shape versus crystal structure**.

1. Notation and the Question

Setting: **a uniformly magnetized body sits in the field it makes itself, and that magnetostatic energy depends on the direction of the magnetization. The effect of shape is written with a demagnetizing factor N.**

$$E_d = \tfrac{1}{2}\mu_0 M_s^2 N, \qquad N_x + N_y + N_z = 1$$

For a thin film N is 1 out of plane and 0 in plane, so the difference between in plane and out of plane is $\tfrac{1}{2}\mu_0 M_s^2$. For a sphere it is $1/3$ in every direction.The crystal's effect is written with the anisotropy constant K_1.

Question: **is the preferred direction of magnetization set by the material, that is the crystal structure, or by the shape?**

2. Sphere and Thin Film

Computation 2.1: **for three materials, the thin-film shape anisotropy and the crystal anisotropy were set side by side in the same units.**

material	saturation magnetization (A/m)	shape anisotropy (J/m^3)	crystal anisotropy (J/m^3) and ratio
iron	1.710×10^{6}	1.837266×10^{6}	4.800×10^{4} (38.276379 times)
cobalt	1.400×10^{6}	1.231504×10^{6}	4.500×10^{5} (2.736676 times)
nickel	4.850×10^{5}	1.477962×10^{5}	4.500×10^{3} (32.843606 times)

For iron and nickel the shape outweighs the crystal by more than thirty times. For cobalt the ratio is 2.736676 and the crystal comes level.

Computation 2.2: for a sphere the demagnetizing factors are $1/3$ in all three directions and sum to exactly 1. Every direction costs the same, so the shape anisotropy came out as 0.

> **Observation 2.3**
>
> **one material divides in two by shape.A sphere of iron is given no direction at all by its shape, and only the crystal's 4.8×10^{4} J/m^3 remains. Make the same iron a film and 1.837266×10^{6} J/m^3 is added——one material, two answers.**

3. Moving the Axial Ratio

Computation 3.1: the shape anisotropy of iron was derived for prolate spheroids of varying axial ratio.

axial ratio	N along the long axis	N across	shape anisotropy (J/m^3)
1 (sphere)	0.333333	0.333333	0
1.5	0.232981	0.383509	2.765597×10^{5}
2	0.173564	0.413218	4.403082×10^{5}
5	0.055821	0.472090	7.647961×10^{5}
10	0.020286	0.489857	8.627273×10^{5}
100	0.000430	0.499785	9.174484×10^{5}

Going from an axial ratio of 10 to 100 raises the shape anisotropy only from 8.627273×10^{5} to 9.174484×10^{5} J/m^{3}. The effect of elongation saturates early.

Computation 3.2: inverting for iron, the shape anisotropy equals the crystal anisotropy of 4.8×10^{4} J/m^{3} at an axial ratio of 1.068187.

> **Observation 3.3**
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> a slight departure from a sphere is enough.A shape stretched by some 7 per cent already gives a direction as strong as the one the crystal structure gives——“not quite round” acts on the same scale as a property of the material.

Computation 3.4: the field needed to turn the magnetization out of the plane is 1.710000×10^{6} A/m for shape alone (equivalent to 2.148849 T), and 4.467507×10^{4} A/m (0.056140 T) for the crystal alone.

4. The Separator

> **Observation 4.1**
>
> the separator is shape versus crystal structure.With the material fixed and only the shape changed, the anisotropy moved from 0 for a sphere to 1.837266×10^{6} J/m^{3} for a film, while the crystal side stayed at 4.8×10^{4} J/m^{3} throughout——which one is acting can be found by making the thing round.

> **Observation 4.2**
>
> beside Paper 419.Paper 419 showed that the same material and shape differ in strength with orientation, and there it was the process that cut the direction in——here the shape itself cuts it. It appears on the drawing and not in the table of materials.

> **Observation 4.3**
>
> what is not said.Domains, domain walls and coercivity are not treated, and the saturation magnetizations and anisotropy constants are room-temperature representative values——what is shown is that the anisotropy of one material moves from 0 to tens of times the crystal’s by shape alone.

5. Roll Call and Closing

1. **iron film 1.837266×10^{6} J/m^{3}** (Computation 2.1): **the effect of shape.**
2. **38.276379 times the crystal** (Computation 2.1): **the core.**
3. **exactly 0 for a sphere** (Computation 2.2): **1/3 in all directions.**
4. **2.736676 for cobalt** (Computation 2.1): **the crystal comes level.**
5. **2.765597×10^{5} at axial ratio 1.5** (Computation 3.1): **it rises on stretching.**
6. **9.174484×10^{5} even at 100** (Computation 3.1): **it saturates early.**
7. **equal at 1.068187** (Computation 3.2): **a 7 per cent stretch.**
8. **2.148849 T to turn it out** (Computation 3.4): **the effect of shape.**
9. **0.056140 T for the crystal** (Computation 3.4): **orders apart.**
10. **shape or crystal** (Observation 4.1): **the separator; Paper 419.**

Closing: **The direction a magnet prefers is not set by its material alone.In an iron thin film the shape anisotropy of 1.837266×10^{6} J/m^{3} stands at 38.276379 times the crystal's, and the same iron as a sphere is given exactly 0 by its shape.Stretch the spheroid and the shape rises, matching the crystal at an axial ratio of 1.068187 for iron; for cobalt the ratio is 2.736676 and the crystal comes level——the anisotropy of one material moves from 0 to tens of times the crystal's by shape alone.The separator is shape versus crystal structure.Placed among the earlier papers——in Paper 419 the process cut a direction into the material; here the shape itself does.To be honest——domains and coercivity are not treated, and the numbers are room-temperature representative values.**

References

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